WIND INPUT, SURFACE DISSIPATION AND DIRECTIONAL PROPERTIES OF SHOALING WAVES
SOURCE TERM BALANCE

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LONG-TERM GOAL

The principal goal of this project is to improve our understanding of the physics interactions which govern the spatial and temporal evolution of surface waves in finite water depths. This will be accomplished through the Shoaling Waves DRI large-scale field experiment. However one term not measurable is the nonlinear wave-wave interaction which will be used to compute energy balance necessary for closure to the transport equation.

SCIENTIFIC OBJECTIVES

The principal objective of this project is to investigate via numerical means the source term balance in shoaling waves. From field measurements obtained in the fall of 1999, and exact solutions to the Boltzmann integral, extensive examination of source term balances will be made. In addition to this, an effort will be made to analyze wave-bottom interactions (from field and numerical studies), and the effects of depth-current induced spectral refraction.

APPROACH

The action balance has two distinct parts to be solved: spatial changes in the spectrum (i.e. propagation shoaling and refraction) and the temporal changes described by the source terms: atmospheric input (S_{in}), nonlinear wave-wave interaction (S_{nl}), dissipation due to whitecapping (S_{ds}), and bottom friction (S_{wb}). The Shoaling Waves DRI field experiment will attempt to directly measure the atmospheric input, whitecapping, and the effect of wave-bottom interactions. The nonlinear interactions will be directly calculated (Quad) in this study. Assessment of the dissipation measurements will be indirectly validated from the source term balance, again numerically computed from all mechanisms. Exact solutions (including the full dispersion relationships) as well as approximations derived from 3GWAM (Komen et al 1994). will be used for the source term balance (adjusting S_{in}, S_{ds}, and S_{wb} derived from the data).

Prior to the Shoaling Waves field experiment (fall 1999), a series of tests will be conducted using 3GWAM, the Exact NL (Hasselmann and Hasselmann 1981), and the Full Boltzmann Model

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(Resio 1993) in the proposed measurement domain. Model results will be evaluated using directional spectra obtained during the DUCK94 experiment (Jensen, 1995).

WORK COMPLETED

High-resolution hydrographic data were obtained from field investigations by various researchers during DUCK94, augmented with historical National Ocean Survey data, and synthesized by J. Dugan (Arete Associates). The domain of this grid extends from 35° to 37° N Latitude, 76° to 74.8° W Longitude at a resolution of approximately 500 m (or 0.25′). 3GWAM was extensively modified so that simulations could be performed on a sub-sampled grid of 0.5′ (or approximately 1 km), as shown in Figure 1.

A multi-level 3GWAM simulation was performed for the intensive measurement period of DUCK94 (1-25 October 1994). A basin scale grid covering the entire Atlantic Ocean (at 1.0° resolution) was nested to a regional domain (0.25° resolution), to a subregion grid (at 0.0833° or about 10 km), and then to the newly constructed grid of 1 km resolution. In addition, this multi-level hindcast provided the basis for developing the infra-structure of a wave forecasting system to be made available during the Shoaling Waves DRI field experiment for planning purposes. This capability was demonstrated during the recent SandyDuck experiment held at the USAE Waterways Experiment Stations' Field Research Facility (FRF) during October 1997 (see http://www.frf.usace.army.mil/sd_prsnt.html).

RESULTS

In the area offshore of the FRF, researchers have generally assumed the bathymetry was gently sloping, and nearly homogeneous alongshore. With recent hydrographic surveys and the compiled grid, this assumption is not longer valid. The initial question poses was how would present wave modeling technologies handle these undulations? From the first year effort, 3GWAM runs with 10 km and 1 km grid resolutions were compared.

A large synoptic-scale storm passed the FRF during DUCK94 (Jensen 1995), producing significant wave heights of nearly 5 m offshore and 4 m at the FRF linear array located approximately 850 m from shore in a water depth of 8.5 m. Variations in integral wave parameters (significant height, mean wave period and direction) between 1 km and 10 km model results at the six measurement sites were at most 0.5 m in the estimate of energy based wave height. However, there was a significant difference in the spatial coverage of heights (Figures 2 and 3). The 4.5 to 5.0 m coverage in the 1 km run extends further to the northwest than in the 10 km simulation. This shrinks the 4.0 to 4.5 m area in the 1 km domain and would create nearly a 0.5 m gradient in the energy based heights between 44006 and 44019 found in the measurements. Despite performing well at the 10 km resolution (Jensen 1995), 3GWAM does better running over this newly defined bathymetry, and the resulting wave estimates clearly demonstrate that high-resolution bathymetry is a necessary requirement for continental shelf model simulations. These results were also evident in a nearshore simulation of the Surface Wave Dynamics Experiment IOP-1 (Cardone et al. 1995).

IMPACT

One views the continental shelf as a complex wave system. The source/sink terms impart their control over changes in the directional spectra while bathymetric effects attempt to steer the energy dictated by local water depth gradients, and ultimately in extremely shallow water, toward a shore-normal direction. What has been found thus far is that by increasing the grid resolution by an order of magnitude, spatial changes of the integral wave characteristics are more pronounced in arbitrary depth. However, based on theoretical constraints integral wave characteristics should be invariant to those conditions. Although only two simulations have been made thus far, and the results are derived on a wave model originally developed for global (i.e. 1.0° resolutions) simulations, the simulations demonstrate the need for:

1. Extensive spatial coverage (obtained from the SWATH Ship, SAR/Interferometric-SAR aircraft overflights, and OSCR) during the Shoaling Waves field experiment;
2. Simulating the domain on a physically appropriate scale is necessary, and;
3. Appropriately simulating all processes, in a consistent space and time scales represented by those processes.

TRANSITIONS

The results obtained from these simulations have been transferred to the Shoaling Waves experimental group for initial planning purposes. The Navy operational forecasting centers (Fleet Numerical Meteorology and Oceanography Center, and the Naval Oceanographic Office) have been briefed on the results of this initial study, and the implications generating nearshore wave forecasts.

RELATED PROJECTS

Listed below are various projects that are directly related to the DRI Shoaling Waves Project. These projects range from applied research, to collaborative work with the Naval Oceanographic Office, and the Department of Defense High Performance Computing Modernization Office.

1. Headquarters, U.S. Army Corps of Engineers: *Modeling the Evolution of Directional Wave Spectra in Arbitrary Water Depths*. Development, investigation, validation of modeling technologies and transition to US Army Corps of Engineers district, division offices, and in-house Coastal and Hydraulics Laboratory staff for use in the estimation of wave conditions in the nearshore domain.

2. Naval Oceanographic Office: Develop, test and transition state-of-the-art wave modeling technologies to the Warfighting Support Center running real time wave forecasts in direct support of Naval operations worldwide.

3. Department of Defense HPC Software Support Initiative (CHSSI) in Climate-Weather-Ocean. Migration of 3GWAM to scalable computational environments. This project's principal goal is to massively parallelize 3GWAM (used by both Navy operational forecast centers) for operational

wave forecasting. The aim is to port this system to new hardware architectures decreasing operational run times by a factor of 2-8 (West, Jensen and Turcotte, 1997).

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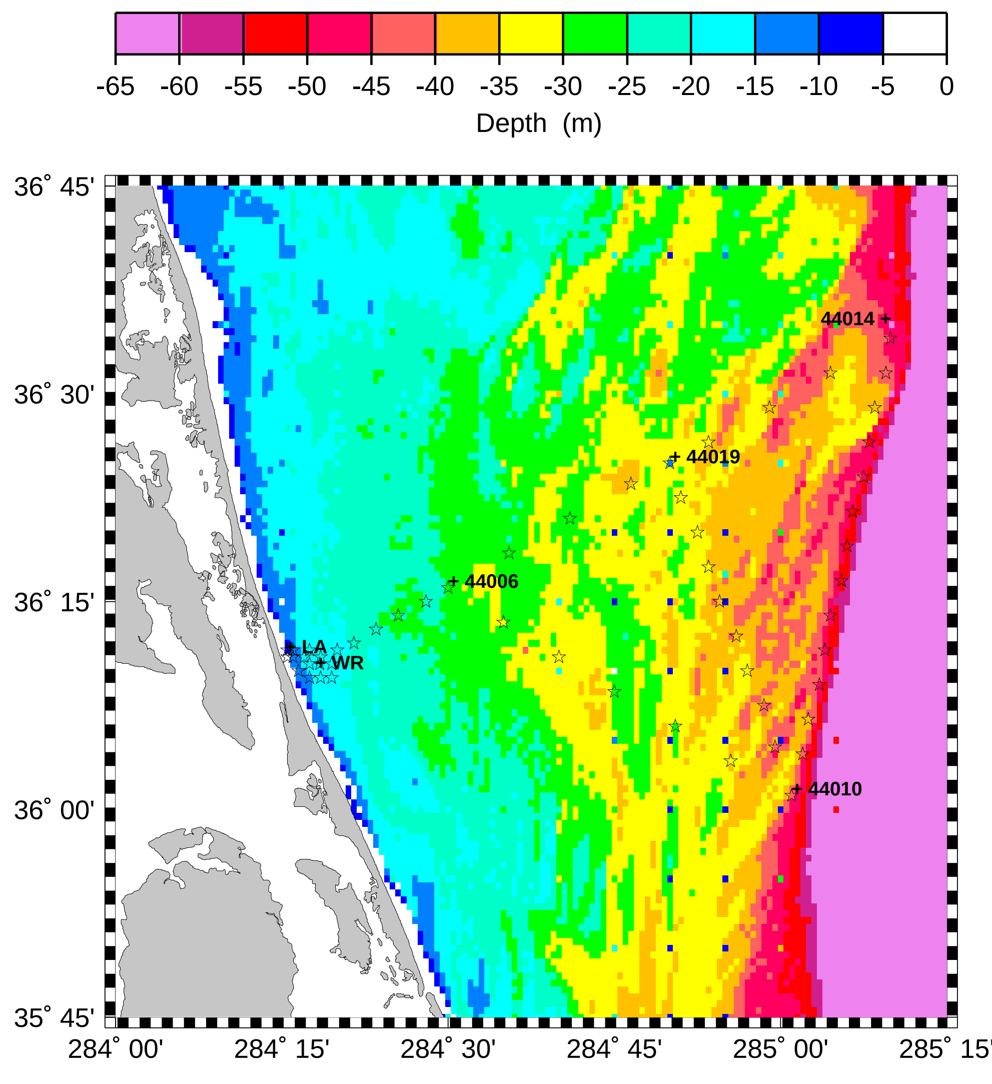

Figure 1. Water Depth Grid (at 1 km resolution) wave measurement sites for DUCK94 (44014, 44019, 44010, 44006 NDBC direction buoys), WR (FRF Waverider), and LA (FRF linear array). The stars identify 3GWAM output locations

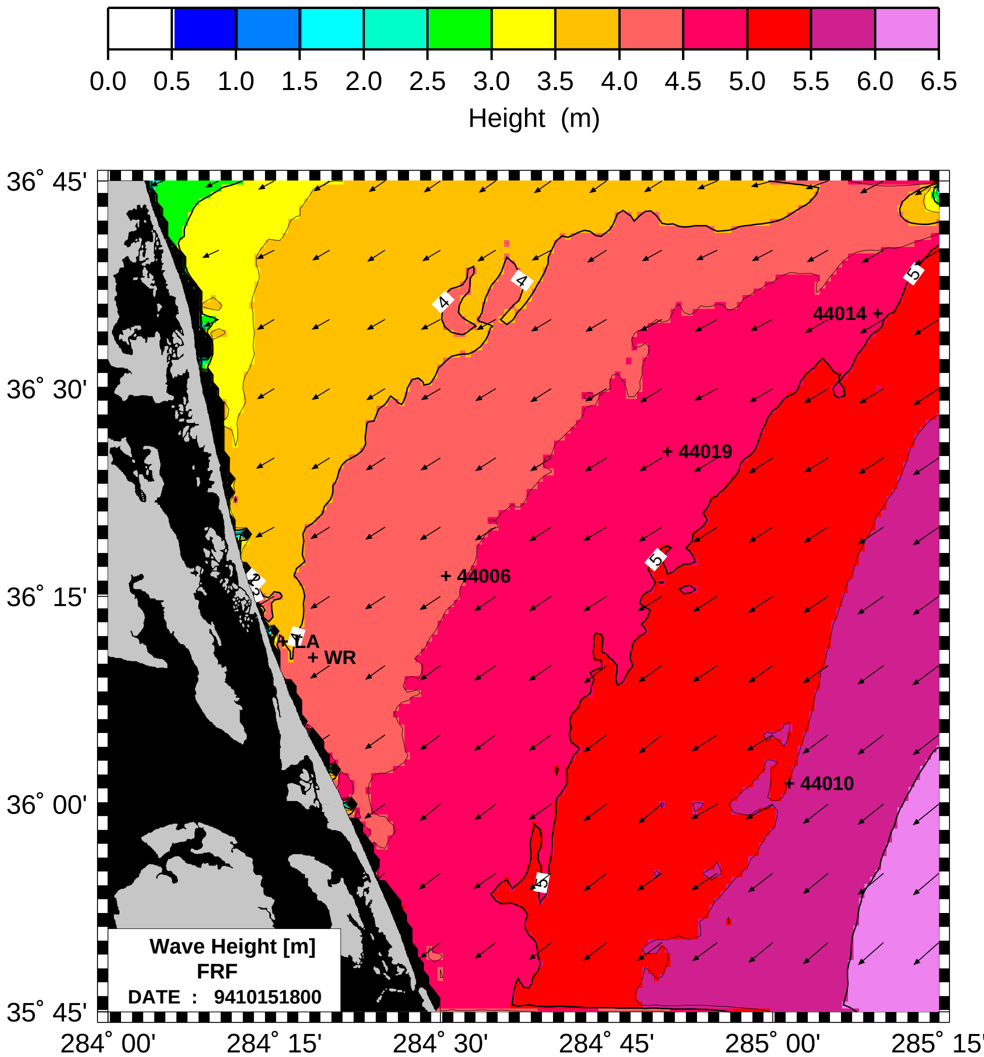

Figure 2. Color wave height contour for 1 km 3GWAM simulation. Mean wave directions identified by arrows.

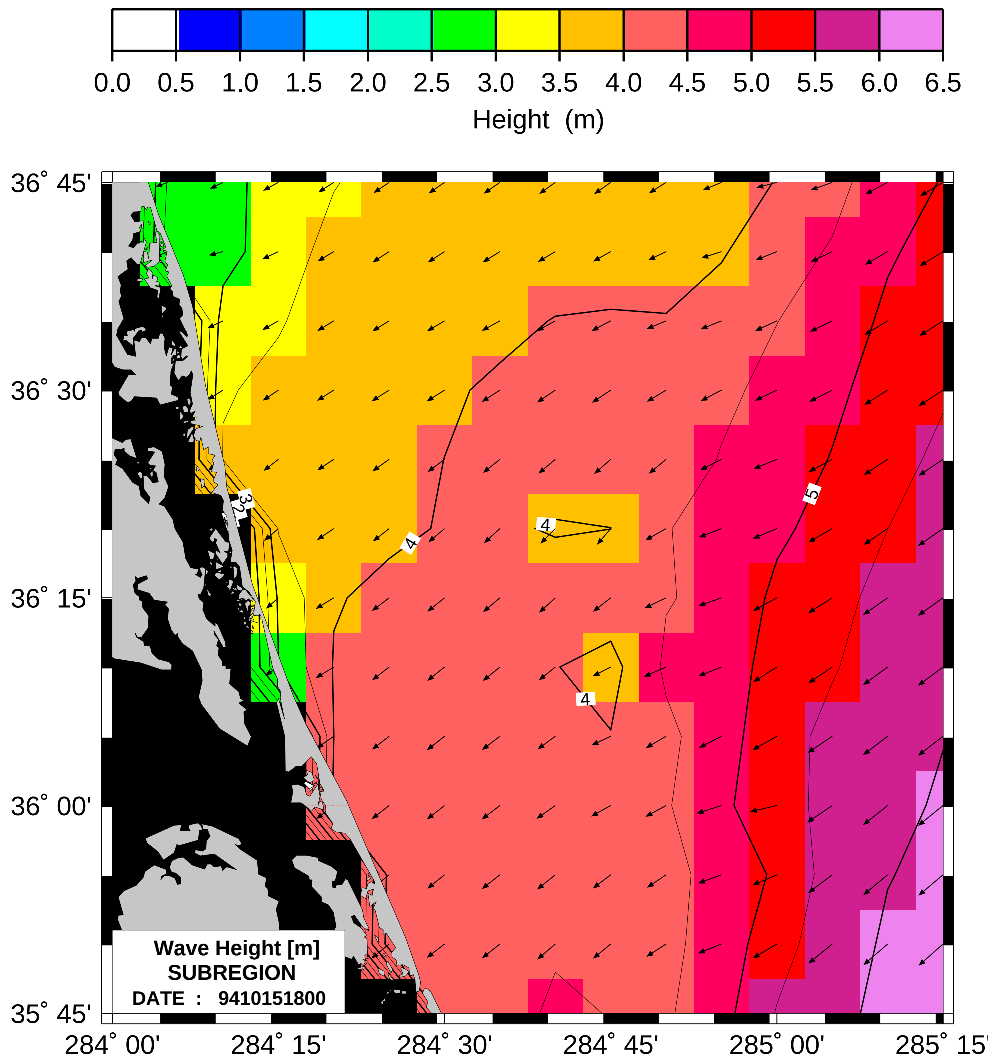

Figure 3. Color wave height contour for 10 km 3GWAM simulations in the domain of the 1km simulation. Mean wave direction identified by arrows.